1967

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Bulletin No. 615

February 1967

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Introduction

The low cost and long service life of flexible polyethylene plastic pipe make it readily adaptable to underground irrigation systems. In 1962 the Louisiana State University Department of Agricultural Engineering initiated a study of small-diameter perforated plastic pipe for injecting water directly into the root zone of plants.

Preliminary calculations of the flow requirements for perforated lines indicated that small-diameter pipe can be used for underground water distribution, and that the pressure required to inject water into the soil mass is of such small magnitude that commercial pipe with perforations cut into it can be used without structural failure of the pipe wall. The size and shape of openings which can be used for releasing water is extremely variable. Zetzsche (*12*),[2] Bryan and Baker (*2*), and Busch and Kneebone (*3*) report the use of drilled holes for water release. Braud (*1*) reports the use of 1/16-inch drilled holes and 1/2-inch longitudinal slits for water release. A longitudinal slit in an elastic pipe wall enlarges when under pressure. When pressure is released the slit tends to close again. Such an opening would likely be self-cleaning, at least for sediment particles the order of size of the slit when open.

A review of literature revealed no applicable information on discharge characteristics of a slit-type orifice in an elastic-wall pipe. The flow rate for an orifice of constant area varies with the square root of pressure. For an elastic orifice, if area increases with pressure the flow rate would be expected to increase more rapidly due to the enlarged area as well as greater pressure.

In order to ascertain the discharge characteristics of longitudinal slits in polyethylene pipe, laboratory calibrations were run using a wide range of slit lengths and pipe sizes. Prediction equations were developed to relate flow rate to pressure, pipe dimensions, and slit length for two types of commercial polyethylene plastic pipe, viz., Type I and Type II polyethylene, as designated by U.S. Department of Commerce Commercial Standard CS197-60.

Physical Properties of Polyethylene

Polyethylene pipe is extruded from virgin polyethylene resin, usually supplied in pellet form. Resistance to weathering is imparted by addition of 2 per cent or more carbon black for absorption of ultraviolet energy.

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[1]Associate Professor of Agricultural Engineering.

[2]Italic numbers in parentheses refer to References, Page 35.

Polyethylene exhibits viscoelastic properties with elastic behavior at room temperatures and increasing viscous behavior at elevated temperatures. The stress-strain curve at ordinary temperatures is similar to that of many true elastic materials. In the region of low stress, strain is proportional to stress for short-term loading. Present pipe design standards specify pipe wall thickness dimensions that limit stress in the pipe wall to values sufficiently low to prevent permanent deformation resulting from long-term loading.

Elastic properties of polyethylene are a function of the density of the resin as well as of temperature. Reding (*7*) gives the stiffness modulus for polyethylene for five densities in the range 0.895 gm/cm³ to 0.968 gm/cm³ and temperatures -150° to 150° C. Stiffness increases with density of the resin at temperatures from 0° to 100° C. Stiffness decreases with rising temperature for all densities. The temperature effect is more pronounced at temperatures above 120° F. Plastic pipe is not recommended for water temperatures above 120° F. At this temperature the pressure rating is 50 per cent of the rating at 73° F.

The American Society for Testing Materials (*6*) recognizes three types of polyethylene according to the density of the base resin in the pipe compound:

Classification	*Density, gm/cm³*
Type I	0.910 to 0.925
Type II	0.926 to 0.940
Type III	0.941 to 0.965.

In the early days of plastic pipe manufacture, low and medium density resins were widely used. They give excellent flexibility but require greater wall thickness for a given pressure rating than high density materials. The trend in pipe manufacturing is now toward high density resins due to the economy of reduced wall thickness, in spite of loss in flexibility (*4*).

Typical values for the modulus of elasticity of polyethylene at 75° F. (*11*) are: Type I — 35,000 psi; Type II — 55,000 psi; Type III — 110,000 psi.

In subsurface irrigation the temperature of the buried pipe does not vary much during the season of use. Soil temperatures during the growing season are usually between 65° and 85° F. at a one-foot depth. For this temperature range a polyethylene plastic line would be expected to exhibit elastic rather than viscous behavior, especially for short-term loading with pressures producing stress much less than the design stress of the pipe resin.

Plastic Pipe Dimensions

A large number of manufacturers produce pipe in conformance with dimensions and tolerances listed in industry-established standards published by the U.S. Department of Commerce.

In 1953 the Society of the Plastics Industry requested the establishment of a commercial standard for dimensions and tolerances for plastic pipe manufacture. The first standard, CS197-54, gave tolerances for standard-wall pipe. Most pipe manufactured in that period utilized low and medium density resins.

In 1957 a revised standard, CS197-57, established three series of pipe wall thicknesses (*8*). Series I dimensions were the same as the CS197-54 standard, with an inside radius-to-minimum wall thickness ratio ranging from 2.85 for 1/2-inch pipe to 3.55 for 1 1/2-inch pipe. Series II dimensions called for a 3.88 radius-to-wall thickness ratio for 1/2-inch pipe and a ratio of near 4.15 for all larger sizes. Recommended maximum working pressure for this series is 75 psi. Series III pipe has a radius-to-wall thickness ratio of 2.8 for all sizes up to 2 inches. Maximum working pressure recommended for this series is 100 psi.

The 1960 standard, CS197-60, (*9*), recognizes the three types of resin defined by the ASTM classification (*6*). Dimensions for Series I pipe remained unchanged from the previous standard. The availability of medium and high density resins—Types II and III—allowed reduced wall thicknesses as specified in this new standard. Working pressure remained at 75 psi for Series II pipe and at 100 psi for Series III.

The pipe specimens used in this study were chosen to represent Type I and Type II resins, which were in widespread use at the time the study was initiated. Test samples were chosen from all three series defined in the 1960 standard in order to effect variation in pipe radius-to-wall thickness ratio, an important variable in the study.

Definition of Variables

Consider a length of plastic pipe with an axial slit cut in its wall section, as shown in Figure 1. If the pipe contains a fluid under pressure, hoop stress in the pipe wall will cause a separation of the pipe along the slit, and discharge through the slit will ensue. For a perfectly formed slit—one with full closure at zero pressure—the width of the opening should be a function of fluid pressure as well as of the structural properties of the pipe wall. Intuitively, one would expect that the shape of the slit when opened by pressure would be somewhat elliptical, at least for a very thin pipe wall. For wall thickness in the order of magni-

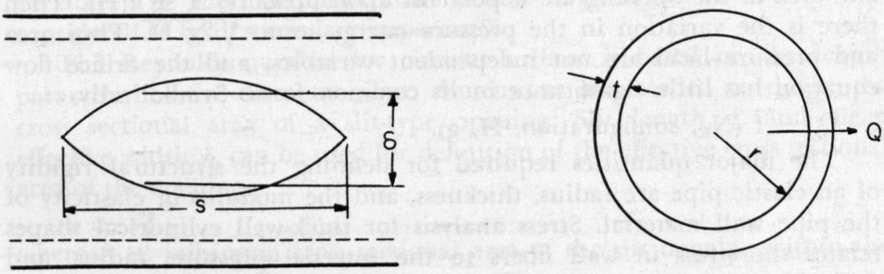

FIGURE 1.—Definition sketch for longitudinal slits in pipe wall. Internal pressure causes separation in pipe wall. Mean slit width $\delta = A/s$, where A is cross-sectional area of slit opening.

tude of commercial polyethylene plastic pipe, however, the shape and size of the opening would vary in the radial direction within the thickness of the pipe wall, due to unequal hoop stress distribution. In effect we are describing an orifice with its area dependent on fluid pressure and elastic behavior of the pipe wall, even though the exact configuration and dimensions of the opening might not be subject to simple definition.

Hydraulically, a slit-type opening, though variable in width along its length, should behave somewhat similarly to a rigid orifice. For a rigid orifice the limiting value of discharge rate is predictable with the relation

$$Q = A\sqrt{2g\ H}$$

where

$Q =$ discharge rate, volume per unit time,
$A =$ area of orifice opening,
$g =$ Newtonian constant,
$H =$ pressure head of the fluid.

Numerous experiments have shown that friction influences and the effects of orifice configuration can be lumped into a coefficient C, $0<C<1$. The value of the coefficient C can be determined by experiment. For a rigid orifice, the coefficient can be related to a flow parameter (the Reynolds number N_R) definitive of the relative magnitude of momentum and viscous effects for the fluid flow through the orifice. Thus, actual discharge rate is related to pressure head by the relation

$$Q = C\ A\sqrt{2g\ H}$$

with $C = f(N_R, \text{configuration})$.

Numerous references give coefficients for circular orifices. These are well known and widely used in flow metering applications. Generally the value of the coefficient varies markedly with low values of the Reynolds number but approaches a constant value for a Reynolds number greater than 10^5.

For a flexible orifice, the effect of pressure changes on discharge rate manifests itself in three ways. The friction coefficient varies with the Reynolds number, which in turn depends on velocity of flow. The shape and area of the opening are dependent upon pressure, $A = f(H)$. Then there is the variation in the pressure energy term, $\sqrt{2g\ H}$. Thus area and pressure head are not independent variables, and the orifice flow equation has little significance in its common form. Symbolically,

$$Q = f\ (N_R, \text{configuration}, H, g).$$

The major quantities required for defining the structural rigidity of an elastic pipe are radius, thickness, and the modulus of elasticity of the pipe wall material. Stress analysis for thick-wall cylindrical shapes relates the stress in wall fibers to the internal pressure, radius, and wall thickness. In an elastic-wall pipe the radius and wall thickness are quantities which affect the deformation of the pipe wall and would likewise affect the size of the opening in a longitudinal slit.

The major quantities which would affect discharge from a slit opening are listed in Table 1. The list includes fluid properties as well as quantities associated with pipe dimensions.

TABLE 1.—Pertinent Quantities for Slit-Type Orifice in Elastic Pipe Wall

No.	Symbol	Quantities	Units	Comment
1.	Q	Discharge rate	gals./min.	Dependent variable for this study.
2.	H	Pressure differential across pipe wall	ft.	
3.	s	Slit length	ft.	Slit is assumed to be completely closed at zero pressure.
4.	t	Pipe wall thickness	ft.	
5.	r	Pipe internal radius	ft.	
6.	δ	Mean slit width	ft.	Slit area, $A = s \cdot \delta$
7.	σ	Fluid density	lbs./ft.^{3}	
8.	ν	Fluid viscosity	lbs./ft.-min.	
9.	E	Modulus of elasticity	lbs./ft.^{2}	Depends on resin density and temperature. For this study taken as discrete quantity for each pipe type.
10.	g	Newtonian constant	ft./sec.^{2}	

For this study it was assumed that the modulus of elasticity of polyethylene pipe would be characterized by the pipe classification, Type I or Type II, and that a generalized prediction relation for discharge rate could be developed for each type based on the other quantities listed. In order to test the assumption, the modulus of elasticity was measured for all pipe specimens to obtain nominal values and was found not to vary over a range of sufficient magnitude for consideration as a major independent variable. Thus for each pipe type the modulus of elasticity was taken as a discrete quantity instead of as a variable. The effect of temperature in the range 65° to 85° F. was also considered to be of secondary importance.

The Reynolds number for circular orifices is based on the length parameter of the diameter. Two dimensions are needed to define the cross sectional area of a slit-type opening. Slit length, s, and mean effective width, δ, can be used for definition of the effective cross sectional area of the opening,

$$A = s \cdot \delta$$

where A = minimum cross sectional area of the slit opening within the pipe wall,

s = slit length,

δ = mean slit width.

The dependent variable in this study is the flow rate, Q, volume per unit of time. Independent variables are pressure, pipe dimensions, slit length, and fluid properties. In functional notation

$Q = f(s, r, t, \sigma, \nu, \delta, H)$ for each pipe type. Quantities are defined in Table 1.

A reduction in the number of independent variables was accomplished by forming dimensionless parameters to define relative slit sizes, s/t, and the relative wall thickness, r/t, of the pipe.

The magnitude of mean slit width would be far less than slit length for most operating conditions of interest. The effect of slit width on fluid energy exchange would be far more significant than the greater dimensions of slit length. For this reason a Reynolds number based on mean slit width was defined as a pertinent variable. Thus the major variables of the slit-type orifice flow system were taken to be Q, s/t, r/t, head H, and a Reynolds number based on slit width. The functional relation is then:

$Q = f(s/t, r/t, N_R, H)$.

Scope of the Study

The objective of this study was to relate discharge rate to the major independent variables for a wide range of values of the independent variables. A series of slit discharge studies was completed and data correlated to give prediction relations for discharge. Separate slit discharge calibrations were run with randomly selected specimens of Type I and Type II commercial polyethylene plastic pipe to develop prediction relations for each type of pipe.

Multiple regression analyses which yielded a multiple correlation coefficient served as a test of the validity of the assumption that a temperature variation of 20° F. and variation in elastic properties due to resin density for randomly selected pipe specimens were of secondary importance.

Experimental Procedure

Twelve pipe specimens purchased from local suppliers were used for slit discharge measurements. As shown in Table 2 the samples represented five brand names, the selection being a matter of local availability rather than adherence to any plan. Data on resin density were obtained from two of the five pipe manufacturers. Pipe classification according to commercial standards was the only criterion used for selecting specimens in the slit testing. Pipe specimens were chosen in 3/8-, 1/2-, 1-, and 1 1/4-inch sizes. No attempt was made to obtain specimens of each type in all sizes.

The elastic modulus of the specimens was evaluated using strain gages and tensile loading. It was found that the elastic moduli of specimens in each type were not of sufficient difference to prohibit the development of generalized prediction equations for each type.

At first a knife blade 0.020 inch thick was used for making slits.

TABLE 2.—Schedule of Pipe Sizes and Slit Lengths

Specimen No.	Manufacturer	Pipe size, inches	Inside diameter, inches	Measured wall thickness, inches	No. of slits	Slit length, inches
			TYPE I PE			
1	E	1/2	0.630	0.065	5	0.315
2	E	1/2	0.630	0.065	5	0.315
9	D	3/8	0.255	0.060	5	0.116
11	D	3/8	0.255	0.060	2	0.127
11	D	3/8	0.255	0.060	2	0.321
11	D	3/8	0.255	0.060	2	0.408
11	D	3/8	0.255	0.060	2	0.696
12	B	1/2	0.622	0.112	4	0.321
			TYPE II PE			
3	C	1 1/4	1.40	0.10	5	0.700
4	A	1/2	0.628	0.061	10	0.315
5	A	1/2	0.628	0.061	5	0.408
6	C	1	1.07	0.076	5	0.408
7	C	1 1/4	1.40	0.10	5	0.408
8	A	1/2	0.628	0.061	5	0.534
10	C	1	1.07	0.076	2	0.127
10	C	1	1.07	0.076	2	0.321
10	C	1	1.07	0.076	2	0.408
10	C	1	1.07	0.076	2	0.696

Three test runs showed erratic behavior attributable to damage to the pipe wall occurred as a result of this slitting technique. The remaining eight specimens were slit with knives made from 0.005-inch blade stock and were held in a special holding device; this technique resulted in a reduced random variation in discharge. Only data from slits made with the 0.005-inch knives were used in deriving prediction relations for slit discharge rates.

Modulus of Elasticity

The pipe specimens slit with 0.005-inch blade stock were of two resin densities in each type. The elastic properties of pipe specimens representing each resin were determined by short-term tensile loading of 12-inch pipe lengths to which strain gages were affixed to detect axial strain in the pipe wall. A stress-strain curve was developed for the elastic region well below yield stress. The modulus of elasticity was taken as the slope of the stress-strain curve (Fig. 2).

Pipe specimens were allowed to adjust to room temperature prior to a test. Weights were hung on the specimens in 5-pound increments for smaller pipe samples and in 10-pound increments for larger ones until

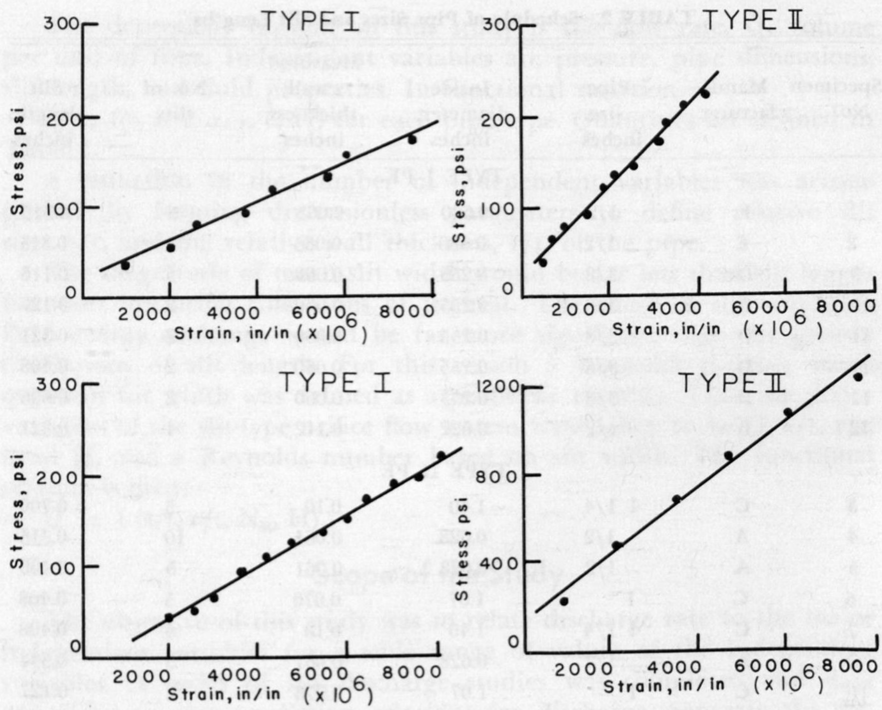

FIGURE 2.—Stress-strain curves for two resins of each pipe type. Curves developed from short-term axial loading of pipe specimens with strain gages attached.

6 to 10 values were produced for developing the elastic curve.

The initial non-linear region of a curve is attributed to flexure of the specimens due to slight original curvature. The specimens were brought to a true straight position after the addition of one or two weights. Strain readings were taken within 1 minute after addition of the weights. Creep with time was evident, especially at the higher stress values.

Since tests were not all conducted at the same room temperature, an estimation of the modulus of elasticity at standard temperature (73.2° F.) was made by plotting the modulus at the known temperatures on the same graph with Reding's (7) extensive modulus-temperature data for polyethylene resins. Then, using Reding's family of curves for a guide, the modulus for the known temperatures at which specimens were tested was adjusted to 73.2° F. as shown in Figure 3.

For Type I specimens the modulus at 73.2° F. was found to be 34,000 psi and 32,500 psi for the two brands of pipe; for Type II pipe both resins had moduli near 70,000 psi. Because of the similarity of stiffness properties for the resin in each pipe type, prediction equations for slit discharge could be attempted based on pooled discharge data of all pipe specimens in each type.

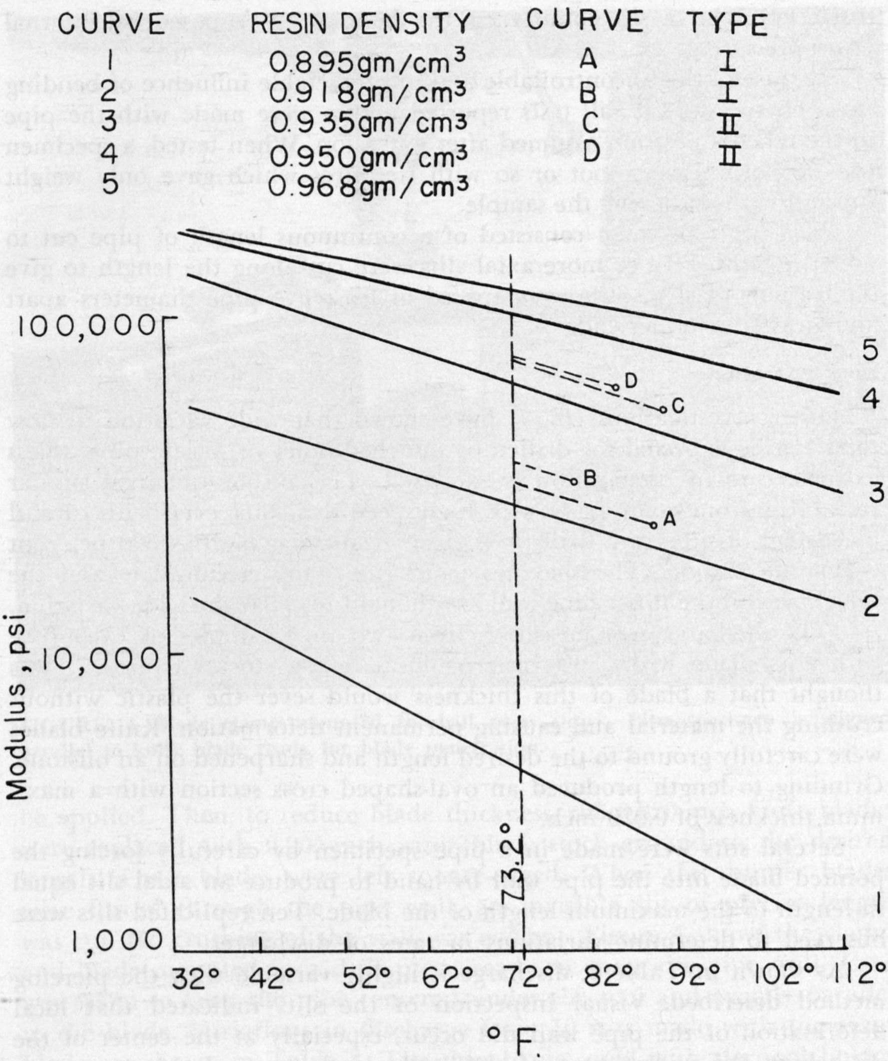

FIGURE 3.—Adjustment of modulus of elasticity to standard temperature 73.4° F. (23° C.). Solid lines are plotted from Reding's data, (7), p. 488, for five resin densities.

Pipe Specimens

Flexible polyethylene pipe is extruded with a slight curvature along its length which allows coiling of the pipe for shipment. In a relaxed position the natural curvature describes a large arc. To bend the pipe into a true straight segment requires only a few pounds of force. A preliminary test of slit discharge indicated that flexing a pipe specimen had a very definite effect on slit discharge rate, as would be expected. Compression of the pipe wall axially causes the slit to enlarge, and axial tensile stress at a slit counteracts the hoop stress imposed by internal water pressure.

Because of the uncontrollable and unpredictable influence of bending stress on the slit size, all tests reported herein were made with the pipe in the relaxed position assumed after extrusion. When tested, a specimen was supported every foot or so with tie wires which gave only weight support without flexing the sample.

Each pipe specimen consisted of a continuous length of pipe cut to 3-foot lengths. Five or more axial slits were cut along the length to give replications of slits. Slits were spaced at least five pipe diameters apart and away from either end.

Slit Preparation

Other investigations (*12, 1*) have shown that wide variation in flow rates can be expected for drilled or punched holes in plastic pipe unless extreme care in preparation is exercised. The author obtained similar variability from holes made with high-speed drill bits, even with careful placement of pipe in a drill press jig. Variation as high as 300 per cent is not uncommon. The shavings which inevitably accumulate and the torn fibers on the inner pipe wall are thought to cause the wide variation.

Flow discharge was measured from two pipe samples of each type with slits made with 0.020-inch penknife blade stock. At first it was thought that a blade of this thickness would sever the plastic without crushing the material and causing permanent deformation. Knife blades were carefully ground to the desired length and sharpened on an oilstone. Grinding to length produced an oval-shaped cross section with a maximum thickness of 0.020 inch.

Several slits were made in a pipe specimen by carefully forcing the pointed blade into the pipe wall by hand to produce an axial slit equal in length to the maximum length of the blade. Ten replicated slits were observed to determine variations in rates of discharge.

As shown in Table 3, discharge is highly variable with the piercing method described. Visual inspection of the slits indicated that local deformation of the pipe wall did occur, especially at the center of the slit where the widest part of the knife blade entered. Measurements showed slit lengths on the inside of the pipe wall varied, probably due to hand movement when the blade was forced through the pipe wall.

To reduce lateral motion of the blade, a clamp was built to attach the knife to the chuck of a drill press so a controlled, steady force could

TABLE 3.—Variation in Discharge from Slits

		Discharge, Milliliters/Minute			
Blade thickness, inches	Test pressure, psi	Range	Mean	Standard deviation	Coefficient of variation, %
0.020	10	22-115	82.5	31.4	38
0.005	32	124-208	183.4	22.0	12

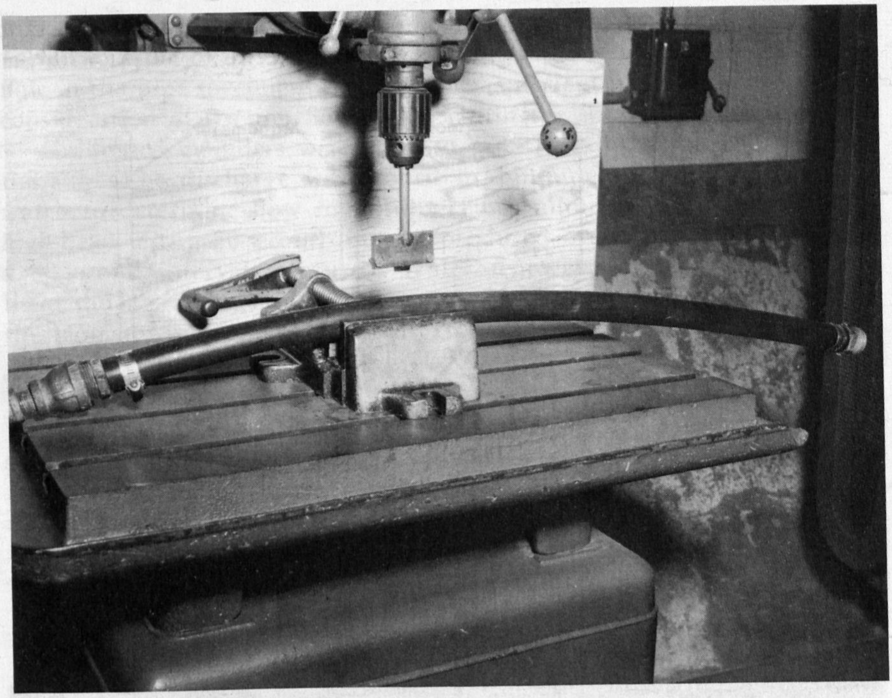

FIGURE. 4—Blade clamp mounted in drill press chuck. Pipe specimen is aligned parallel to knife blade ready for blade penetration.

be applied. Then, to reduce blade thickness, the 0.020-inch knife blades were replaced with 0.005-inch razor blade stock ground to the desired length. These blades were left square-edged. When the thinner blades were forced through the pipe wall, an invisible slit of precise length was cut. No crushing of the wall was evident. Figure 4 shows the clamp and blade mounted in a drill press, ready to enter the pipe wall. Care was taken to keep the pipe centered under the tool and exactly parallel to the blade. Variations in discharge from 10 slits made with the razor blade are shown in Table 3. The thin blade, used with the tool holder in a drill press, greatly reduced variations in discharge.

The slit produced by the 0.005-inch blade stock was assumed to be a true slit with no opening at zero pressure. Discharge prediction results presented in this report were derived from slits made with the 0.005-inch blade stock. Data from three pipe specimens with slits made by the thicker blade were used for a rough check on the validity of the prediction equations derived from thin-blade slits.

Hydraulic Test Facility

The LSU anhydrous ammonia equipment test facility furnished a convenient water supply with flow and pressure instrumentation. A 1,000-gallon water tank pressurized with a regulated air supply provided a constant head water supply (Fig. 5). Supply pressure was constant within 0.1 psi during a run. A mercury manometer, 0 to 50 psi with 0.1

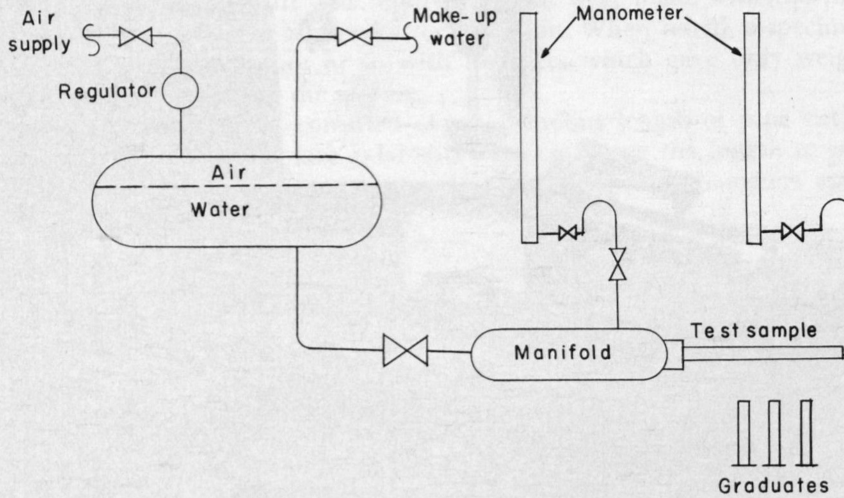

FIGURE 5.—Schematic diagram of hydraulic test facility.

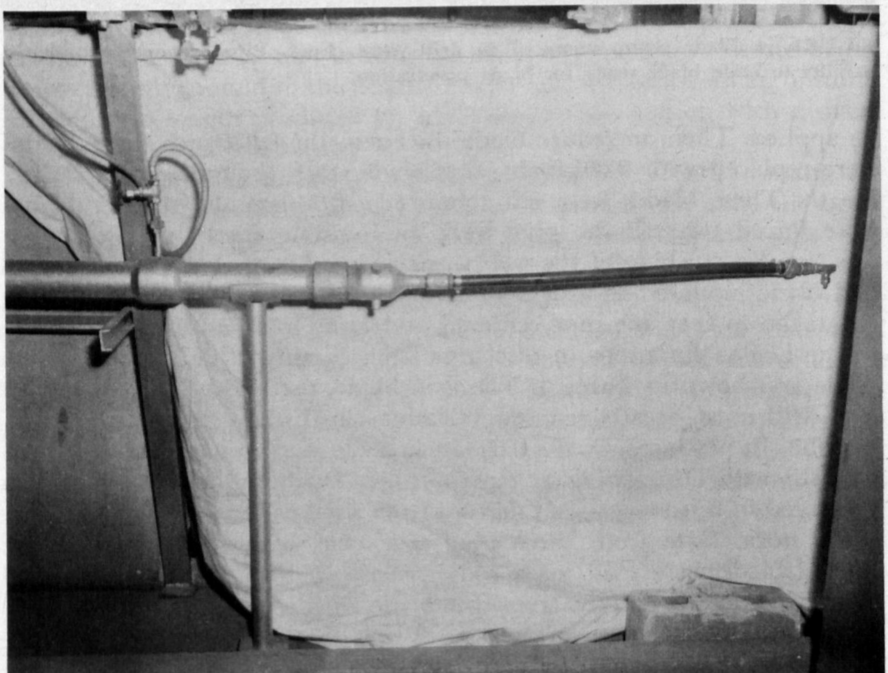

FIGURE 6.—Slit pipe specimen ready for discharge measurement. Five or more replicated slits were used with each pipe specimen. Piezometer was connected to end of specimen for precise head measurement.

psi subdivisions, was used for head measurements. A piezometer was connected to pipe specimens for head readings below 4 psi. The velocity of flow in the pipe specimens never reached sufficient magnitude to warrant consideration of friction flow losses within the short pipe lengths.

Graduated cylinders were used to catch the discharge issuing from the slits. The discharge was timed in 1-minute intervals with a stop watch to determine flow in milliliters per minute. For some large-slit, high-head tests a 30-second interval produced over 1,000 milliliters, and a 30-second interval was used. Water temperature, which varied but little during a day's testing, was measured by immersing a mercury thermometer in a beaker of effluent from one of the slits.

Test Procedure

Standard pipe adaptors and fittings were used to connect a pipe specimen to the supply manifold and the piezometer tube. For a test run after the specimen was installed the manometer and piezometer were zeroed and readied and the supply pressure was gradually increased by

TABLE 4.–Schedule of Values of Independent Variables for Which the Discharge Rate Was Measured

Pipe specimen No.	No. slits	s/t	r/t	Head, psi: No. of values	Head, psi: Range	Reynolds number range	No. observations of discharge Q
				Type I PE Pipe			
1*	5	4.51	4.51	10	1 to 50	205 to 3,242	50
2*	15	4.51	4.51	2	10 to 50	66 to 3,057	30
9	5	1.93	2.12	6	18 to 45	5 to 442	30
11	2	2.12	2.12	4	5 to 26	5 to 37	8
11	2	5.33	2.12	4	5 to 26	79 to 551	8
11	2	6.80	2.12	4	5 to 26	72 to 811	8
11	2	11.60	2.12	4	5 to 26	68 to 237	8
12	4	3.14	3.14	7	1 to 50	3 to 1,272	28
				Type II PE Pipe			
3*	5	7.60	7.06	7	1 to 10	9 to 1,597	35
4	10	5.23	5.14	3	4 to 33	61 to 919	30
5	5	6.69	5.14	5	5 to 30	78 to 1,182	25
6	5	5.83	7.65	7	7 to 45	4 to 2,793	35
7	5	4.43	7.06	5	18 to 41	64 to 3,076	25
8	4	8.59	5.14	4	5 to 20	197 to 2,744	16
10	2	1.81	7.65	4	8 to 30	5 to 23	9
10	2	4.56	7.65	4	8 to 30	5 to 63	8
10	2	5.83	7.65	4	8 to 30	205 to 532	8
10	2	9.94	7.65	4	8 to 30	93 to 2,634	8

*Slits made with 0.020-inch blade. Discharge data for these specimens not used in determination of prediction equations because of wide variation in discharge due to imperfect slit formation.

opening the supply valve. Flow discharge did not begin immediately; some slits would exhibit a tenacious water drop while others dripped water slowly until a threshold pressure—later found to be predictable—was reached. Then a sharp flat jet issued from the slits. The discharge from each of five or more replicated slits was caught simultaneously in graduated cylinders during the timed interval. Five samples of Type I pipe and seven samples of Type II were tested with the combination of slit sizes and pressures shown in Table 4. For Type I pipe, the values of relative slit sizes used ranged from 1.93 to 11.60; for Type II the range was from 1.81 to 9.94. Values of r/t were not subject to manipulation because they are dictated by manufactured pipe dimensions.

Water temperature for most runs was in the range 70° to 75° F. However, for one run on a cold day it dropped to 63° F. The highest temperature experienced was 85° F.

Results

Flow Regimes

In all tests it was found that two distinct types of flow could issue from a slit, depending on pressure and relative slit length. Drip flow, wherein surface tension and viscous forces were apparently dominant over dynamic forces, always resulted with low pressure and relatively small slit length. Drip flow would persist until a certain pressure was reached, above which discharge was characterized by a clean, sharp jet issuing from the slit (Fig. 7). Sufficient observational data were gathered to define the regions of pressure and relative slit length definitive of the two flow regimes.

The ratio of slit length to wall thickness, s/t, was found to be an adequate parameter for defining relative slit size. When the value of s/t for drip flow observations was plotted against pressure, a characteristic drip flow region was described for each pipe type as shown in Figures 8 and 9. In some of the tests the actual threshold pressure for transition to jet flow was found. However, the threshold pressure should not be taken as an exact value since the curves in Figures 8 and 9 were derived from a limited number of observations.

Actually, there was evidence of a transition region in which flow might be either drip or jet, depending on whether pressure was increasing or decreasing. With increasing pressure, flow remained drip type until the maximum pressure possible, the threshold value, was reached. For a decreasing pressure situation starting in the jet flow region, there was a tendency for slits to remain open even after pressure dropped below the threshold value. The change from jet to drip flow with decreasing pressure occurred at pressure values as much as 20 per cent below the threshold for transition with increasing pressure.

A Reynolds number based on mean slit width was found to be an indication of the type of flow—drip or jet—which would issue from a slit. During a test run the mean slit width was not subject to direct measure-

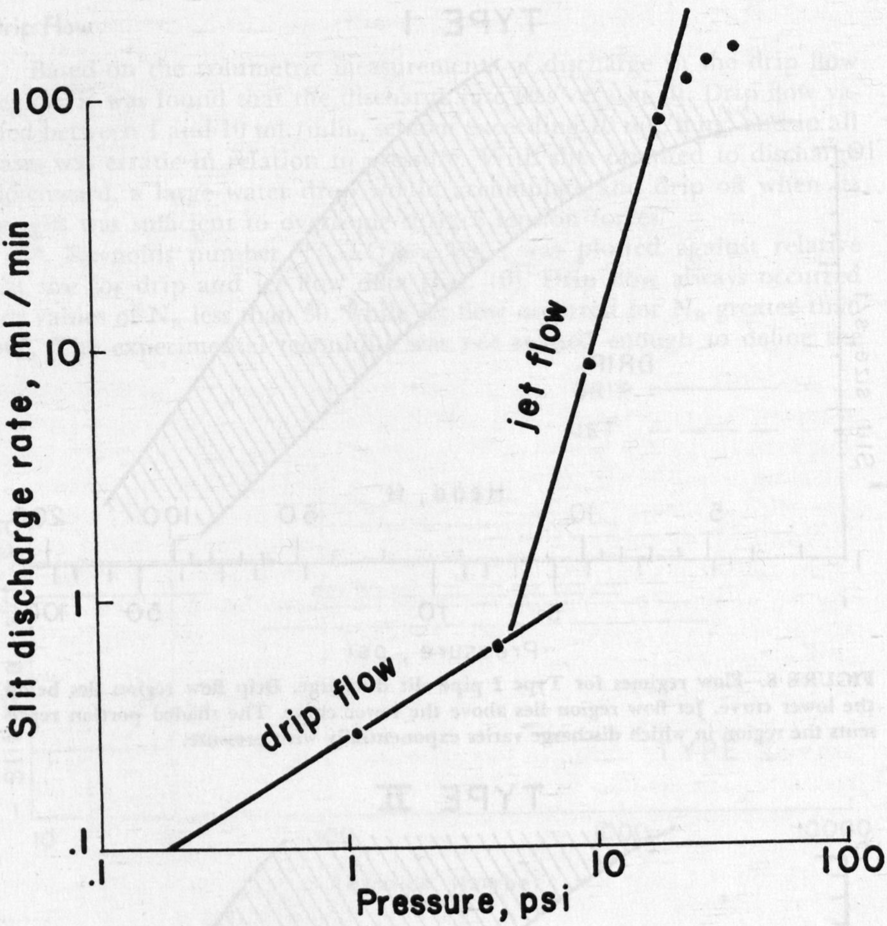

FIGURE 7.—Discharge versus pressure head for a typical slit-type orifice in elastic-wall pipe. Two distinct types of flow are apparent: drip flow and jet flow.

ment; however, a Reynolds number based on it could be calculated indirectly by use of the continuity equation and the definition of the mean slit width. The discharge rate Q equals AV, where A is the cross-sectional area of the slit and V is the average velocity at A. The mean slit width is related to length and area, $A = s\delta$, (Fig. 1) so that

$$Q = AV = s\delta V.$$

A Reynolds number for discharge,

$$N_R = V\delta/\nu = Q/s\nu,$$

could be computed from known values of Q, s, and ν.

The range of Reynolds number values encountered in the experiments is given in Table 4.

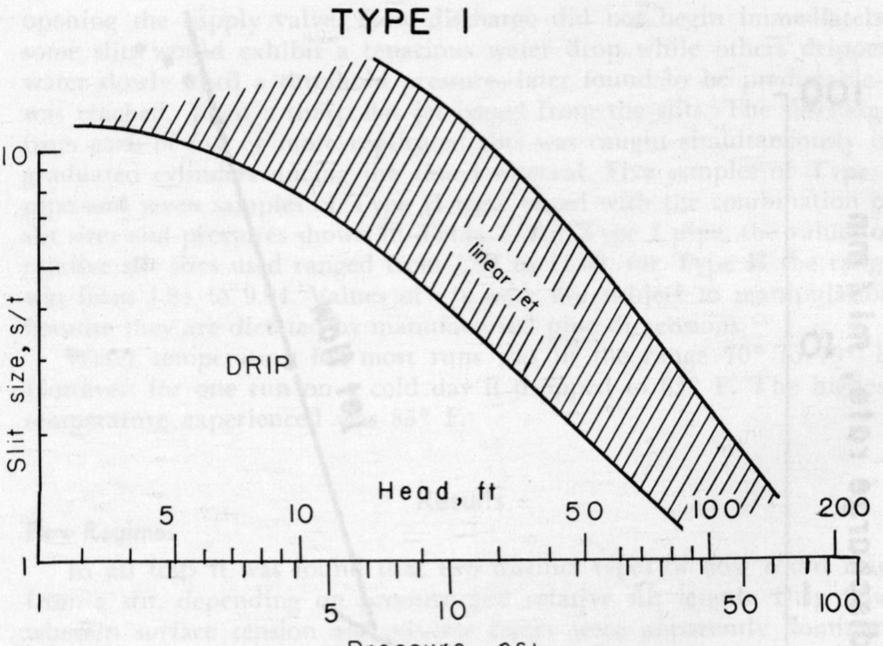

FIGURE 8.—Flow regimes for Type I pipe slit discharge. Drip flow region lies below the lower curve. Jet flow region lies above the lower curve. The shaded portion represents the region in which discharge varies exponentially with pressure.

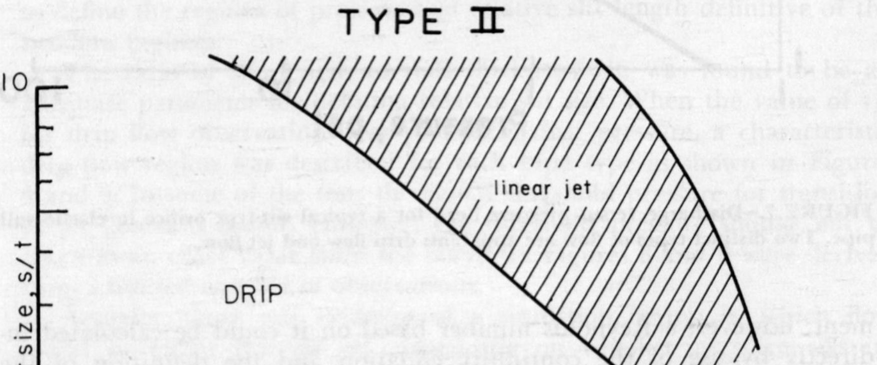

FIGURE 9.—Flow regimes for Type II pipe slit discharge. Drip flow region lies below the lower curve. Jet flow region lies above the lower curve. The shaded portion represents the region in which discharge varies exponentially with pressure.

Drip Flow

Based on the volumetric measurements of discharge in the drip flow region, it was found that the discharge rate was very small. Drip flow varied between 1 and 10 ml./min., seldom exceeding 10 ml./min., and in all cases was erratic in relation to pressure. With slits oriented to discharge downward, a large water drop would accumulate and drip off when its weight was sufficient to overcome surface tension forces.

A Reynolds number, $N_R = Q/s\nu = V\delta/\nu$, was plotted against relative slit size for drip and jet flow data (Fig. 10). Drip flow always occurred for values of N_R less than 30, while jet flow occurred for N_R greater than 100. The experimental technique was not refined enough to define the

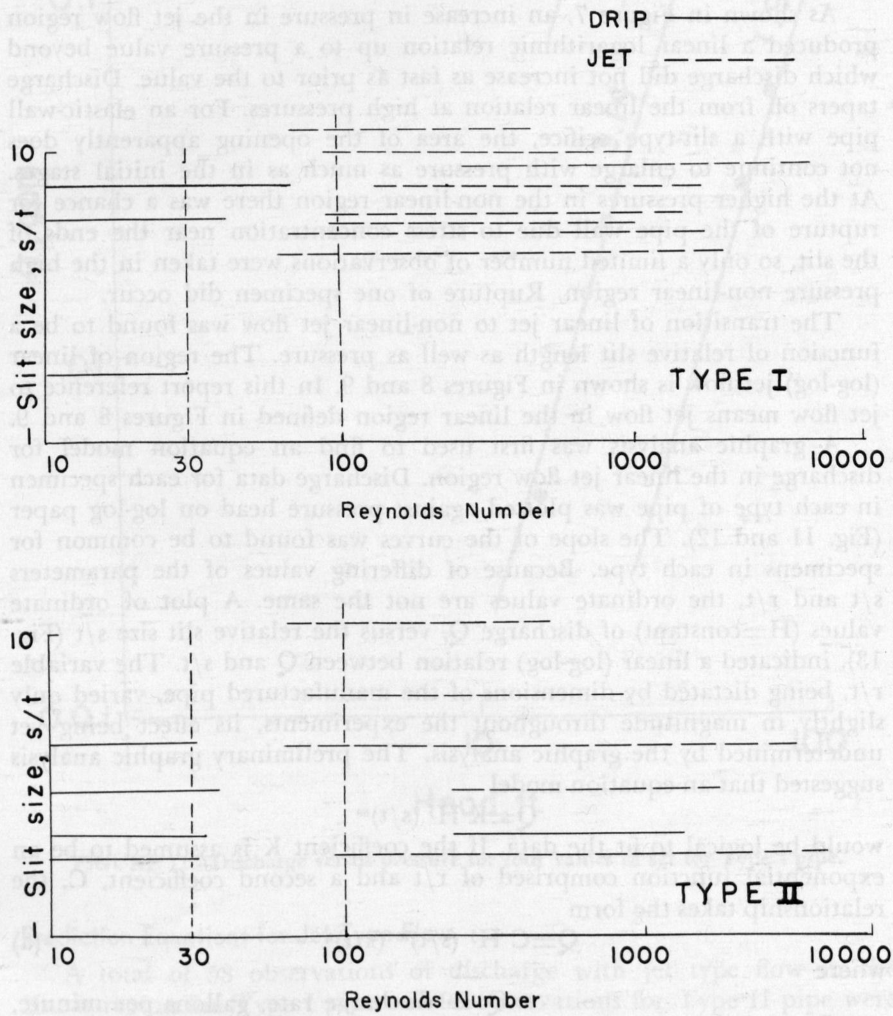

FIGURE 10.—Reynolds number for drip and jet flow. Plotted values represent data from slits made with both 0.020- and 0.005-inch-thick blades.

region $30 < N_R < 100$ as other than a broad region of transition. In many cases, however, plotted minimum values for jet flow in Figure 10 do represent the lowest value of N_R for which jet flow could be established. The Reynolds number range for the transition region appears to be independent of relative slit size s/t and common for both types of pipe.

The drip and jet flow regime defined by the s/t - pressure values (Fig. 8 and 9) was common for discharge from slits made with both the 0.020-inch blades and the thin 0.005-inch blades. Relative surface tension to dynamic force effects were thought to be similar for both slit types.

Jet Flow

As shown in Figure 7, an increase in pressure in the jet flow region produced a linear logarithmic relation up to a pressure value beyond which discharge did not increase as fast as prior to the value. Discharge tapers off from the linear relation at high pressures. For an elastic-wall pipe with a slit-type orifice, the area of the opening apparently does not continue to enlarge with pressure as much as in the initial stages. At the higher pressures in the non-linear region there was a chance for rupture of the pipe wall due to stress concentration near the ends of the slit, so only a limited number of observations were taken in the high pressure non-linear region. Rupture of one specimen did occur.

The transition of linear jet to non-linear jet flow was found to be a function of relative slit length as well as pressure. The region of linear (log-log) jet flow is shown in Figures 8 and 9. In this report reference to jet flow means jet flow in the linear region defined in Figures 8 and 9.

A graphic analysis was first used to find an equation model for discharge in the linear jet flow region. Discharge data for each specimen in each type of pipe was plotted against pressure head on log-log paper (Fig. 11 and 12). The slope of the curves was found to be common for specimens in each type. Because of differing values of the parameters s/t and r/t, the ordinate values are not the same. A plot of ordinate values (H=constant) of discharge Q, versus the relative slit size s/t (Fig. 13), indicated a linear (log-log) relation between Q and s/t. The variable r/t, being dictated by dimensions of the manufactured pipe, varied only slightly in magnitude throughout the experiments, its effect being yet undetermined by the graphic analysis. The preliminary graphic analysis suggested that an equation model

$$Q = K\, H^{j}\, (s/t)^{m}$$

would be logical to fit the data. If the coefficient K is assumed to be an exponential function comprised of r/t and a second coefficient, C, the relationship takes the form

$$Q = C\, H^{j}\, (s/t)^{m}\, (r/t)^{n} \qquad \text{(a)}$$

where

Q = discharge rate, gallons per minute,
C = a coefficient to be evaluated,
j, m, n = exponents to be evaluated.

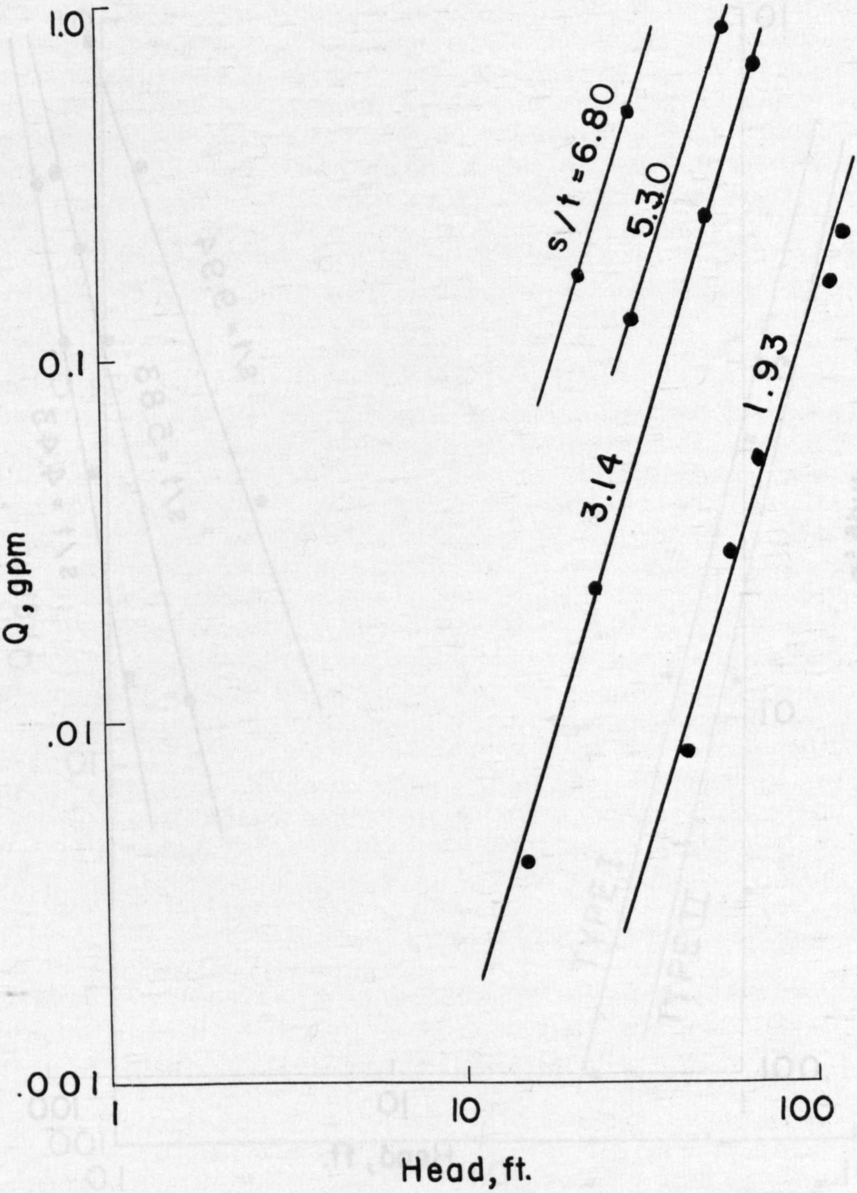

FIGURE 11.—Discharge versus pressure for four values of s/t for Type I pipe.

Prediction Equations for Jet Type Flow

A total of 58 observations of discharge with jet type flow in the linear region for Type I pipe and 96 observations for Type II pipe were available for analysis.

For the jet flow data for each type of pipe, multiple regression

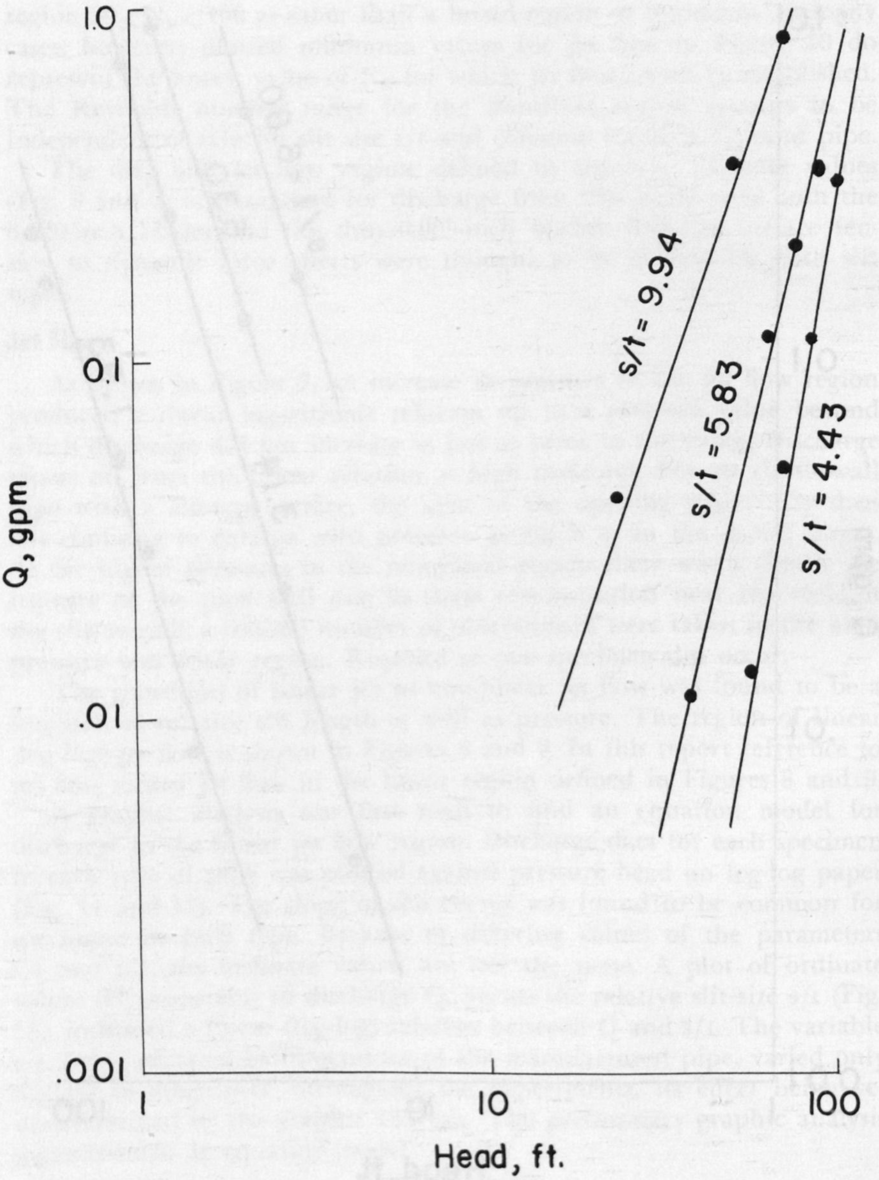

FIGURE 12.—Discharge versus pressure for three values of s/t for Type II pipe.

analyses were used for evaluating the coefficient and exponents for equation (a). Data were analyzed with an electronic digital computer using a standard multiple regression program.

The program first changes the model to linear equation form with logarithmic transformation and then performs the regression analysis.

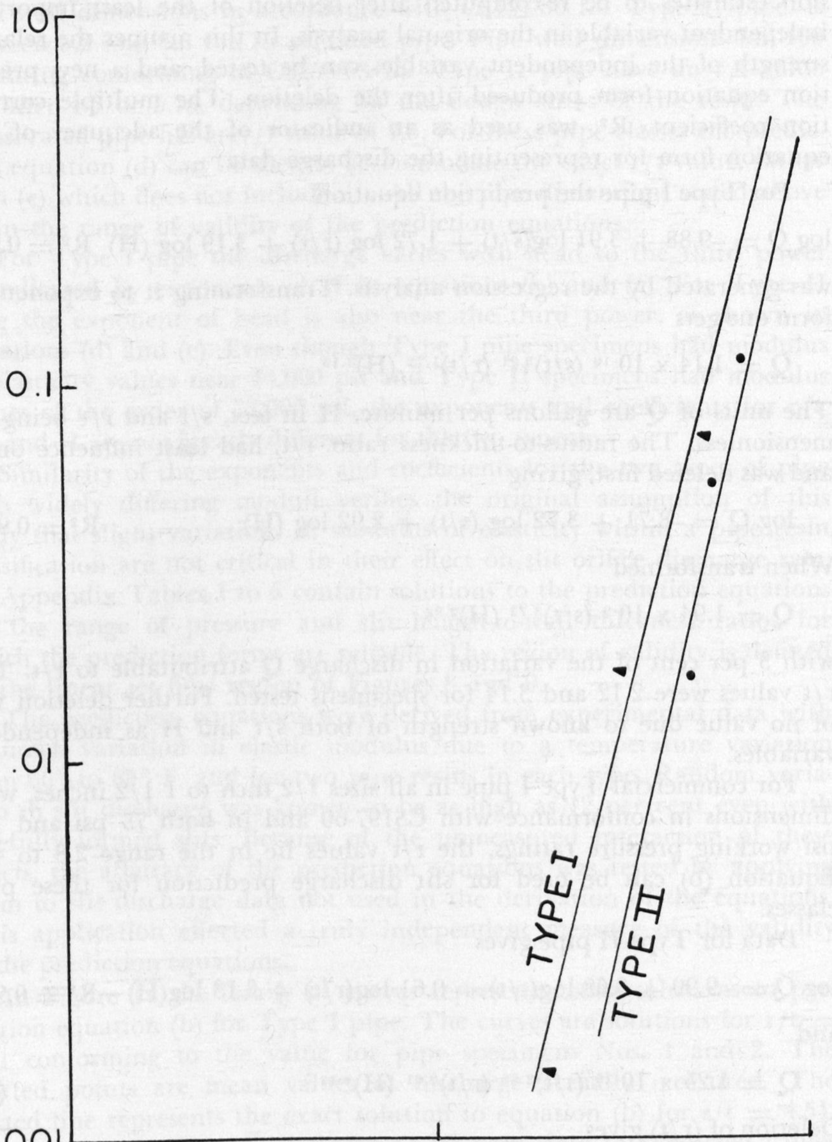

FIGURE 13.—Discharge versus s/t for constant pressure, H = 50 feet.

For each analysis a multiple correlation coefficient is given for the linear equation of logarithms.

An automatic deletion feature built into the program allows regression estimates to be re-computed after deletion of the least important independent variable in the original analysis. In this manner the relative strength of the independent variables can be tested, and a new prediction equation form produced after the deletion. The multiple correlation coefficient, R^2, was used as an indicator of the adequacy of the equation form for representing the discharge data.

For Type I pipe the prediction equation

$$\log Q = -9.88 + 3.91 \log(s/t) + 1.72 \log(r/t) + 3.19 \log(H) \quad R^2 = 0.950$$

was generated by the regression analysis. Transforming it to exponential form one gets

$$Q = 1.14 \times 10^{-10} (s/t)^{3.91} (r/t)^{1.72} (H)^{3.19} \tag{b}$$

The units of Q are gallons per minute, H in feet, s/t and r/t being dimensionless. The radius-to-thickness ratio, r/t, had least influence on Q and was deleted first, giving

$$\log Q = -8.71 + 3.72 \log(s/t) + 2.92 \log(H) \qquad R^2 = 0.920.$$

When transformed

$$Q = 1.94 \times 10^{-9} (s/t)^{3.72} (H)^{2.92} \tag{c}$$

with 3 per cent of the variation in discharge Q attributable to r/t. The r/t values were 2.12 and 3.14 for specimens tested. Further deletion was of no value due to known strength of both s/t and H as independent variables.

For commercial Type I pipe in all sizes 1/2 inch to 1 1/2 inches, with dimensions in conformance with CS197-60 and in both 75 psi and 100 psi working pressure ratings, the r/t values lie in the range 2.8 to 4.2. Equation (b) can be used for slit discharge prediction for these pipe classes.

Data for Type II pipe gives

$$\log Q = -9.90 + 3.68 \log(s/t) + 0.61 \log(r/t) + 3.13 \log(H) \quad R^2 = 0.920$$

and

$$Q = 1.25 \times 10^{-10} (s/t)^{3.68} (r/t)^{0.61} (H)^{3.13} \tag{d}$$

Deletion of (r/t) gives

$$\log Q = -9.32 + 3.55 \log(s/t) + 3.14 \log(H) \qquad R^2 = 0.915$$

and

$$Q = 4.70 \times 10^{-10} (s/t)^{3.55} (H)^{3.14} \tag{e}$$

Very little reduction in R^2 occurred with deletion of r/t. The variation in Q was highly independent of r/t for the narrow range of values encountered in the experiments, r/t = 5.14 and r/t = 7.65. The r/t value for all commercial pipe sizes from 1/2 inch to 1 1/2 inches, extruded with wall dimensions in accordance with CS197-60 for Type II pipe, is between 5.2 and 5.8 for 75 psi-rated pipe. Pipe wall dimensions for 100 psi rating conforming to CS255-63 for Type II pipe have an r/t value of either 4.5 or 5.75, depending on the design stress of the resin. The 80 psi-rated pipe has an r/t value of 7.5. For these pipe classes the prediction equation (d) can be used to accommodate the exact r/t value, rather than (e) which does not include r/t. All the pipe dimensions stated above lie in the range of validity of the prediction equations.

For Type I pipe the discharge varies with head to the third power as indicated by exponents of H in equations (b) and (c). For Type II pipe the exponent of head is also near the third power, as shown in equations (d) and (e). Even though Type I pipe specimens had modulus of elasticity values near 34,000 psi and Type II specimens had modulus values of the order of 72,000 psi, the exponents and coefficients for r/t, s/t, and H are not greatly different for the two types.

Similarity of the exponents and coefficients for the two types of pipe with widely differing moduli verifies the original assumption of this study that slight variations in modulus of elasticity within a pipe resin classification are not critical in their effect on slit orifice discharge rate.

Appendix Tables 1 to 6 contain solutions to the prediction equations for the range of pressure and slit length-to-wall thickness ratios for which the prediction forms are reliable. The region of validity is defined by the linear jet flow region of Figures 8 and 9.

The prediction equations were derived from experimental data with a known variation in elastic modulus due to a temperature variation from 60° to 85° F. and for two pipe resins in each type. Random variation in slit discharge was known to be as high as 12 per cent even with carefully formed slits. Because of the unmeasured interaction of these effects, the accuracy of the prediction equations was tested by applying them to slit discharge data not used in the derivation of the equations. This application effected a truly independent measure of the validity of the prediction equations.

In Figure 14 the family of curves represents exact solutions to prediction equation (b) for Type I pipe. The curves are solutions for $r/t = 4.51$ conforming to the value for pipe specimens Nos. 1 and 2. The plotted points are mean values of discharge actually measured. The dotted line represents the exact solution to equation (b) for $s/t = 4.51$. The measured values of discharge Q lie very close to predicted values represented by the dotted line. This result shows excellent agreement in observed and predicted values.

For Type II pipe, prediction equation (d) is plotted in Figure 15 with $r/t = 7.06$ corresponding to pipe specimen No. 3 which was not used in the generation of the equation. Plotted points for measured values of the discharge rate lie near predicted values (the dotted line) for the lower pressure region. At the higher pressure region, agreement is poor; however, it should be remembered that discharge data for pipe specimen No. 3 came from slits with known permanent knife damage.

These slits had visible openings at zero pressure, and thereby exhibited a larger cross-sectional area and greater discharge at all pressures.

Comparison of actual observation of flow values Q with predicted

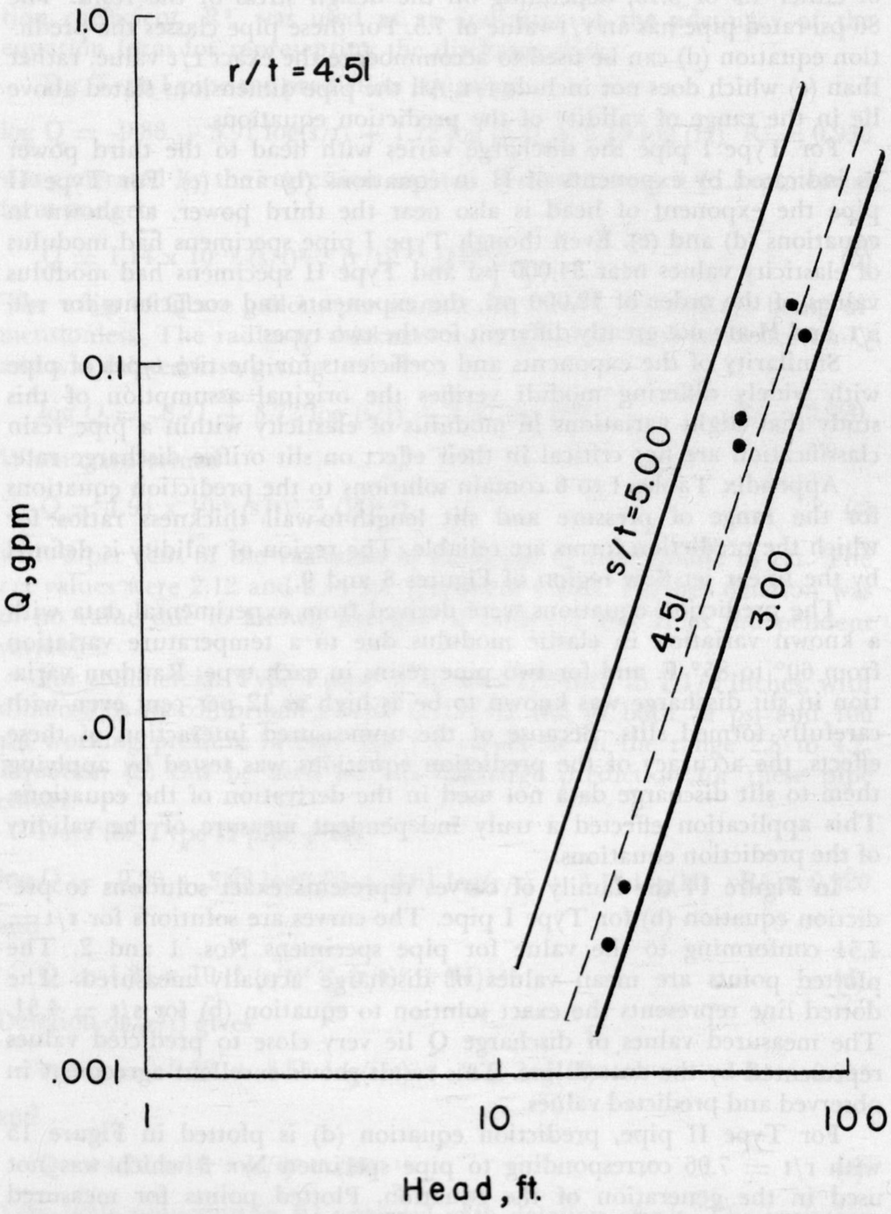

FIGURE 14.—Comparison of predicted values of discharge to measured values for Type I pipe. Solid lines represent solutions to equation (b). Dotted line is solution with s/t = 4.51. Plotted points are measured values of discharge from pipe specimens Nos. 1 and 2.

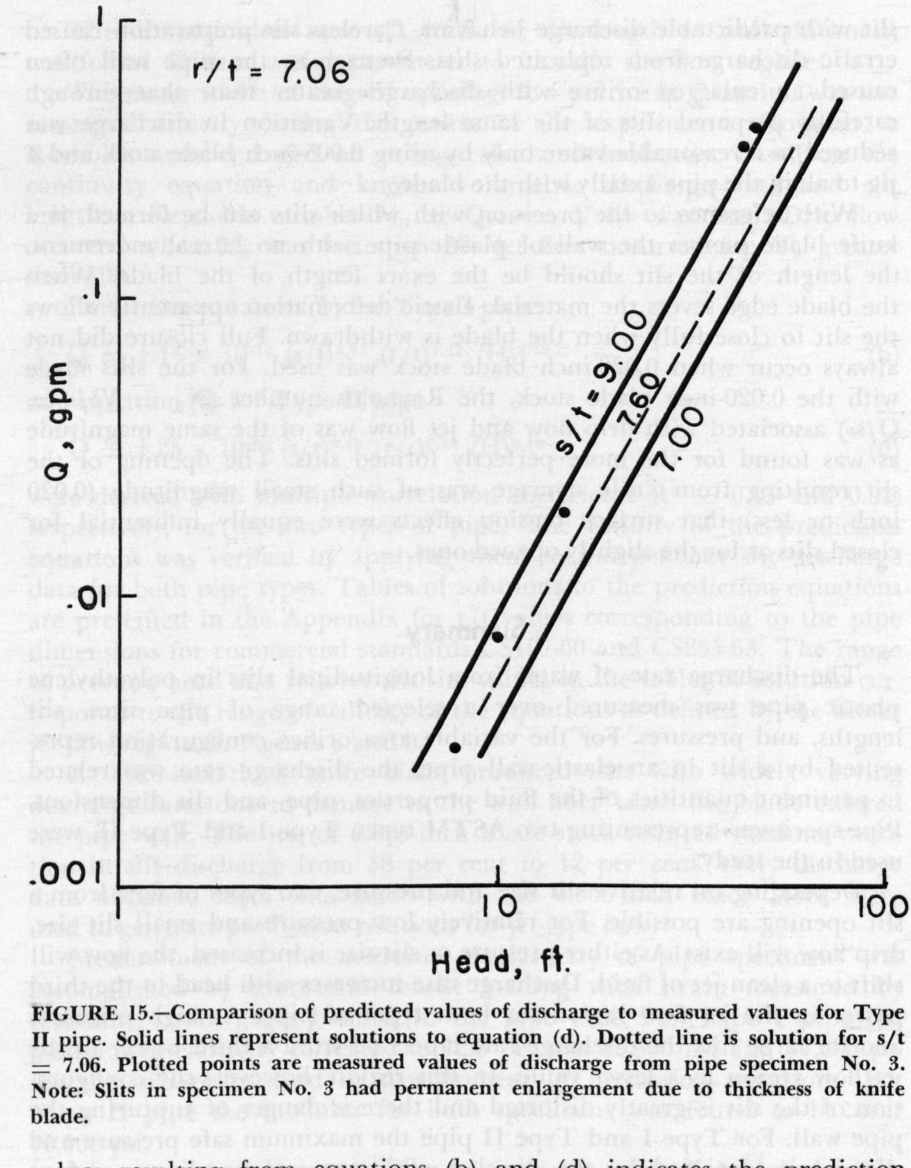

FIGURE 15.—Comparison of predicted values of discharge to measured values for Type II pipe. Solid lines represent solutions to equation (d). Dotted line is solution for s/t = 7.06. Plotted points are measured values of discharge from pipe specimen No. 3. Note: Slits in specimen No. 3 had permanent enlargement due to thickness of knife blade.

values resulting from equations (b) and (d) indicates the prediction equations are valid predictors of discharge. High correlations ($R^2 > 0.90$) give further evidence of the adequacy of the equation form with the three independent variables. The variation attributable to elastic properties of the resin and to temperature apparently did not greatly affect the discharge through slit openings.

The Effect of Knife Damage on Slit Discharge

In this investigation it was found that a thin, sharp knife blade, carefully pushed through the pipe wall, was required for producing a slit with predictable discharge behavior. Careless slit preparation caused erratic discharge from replicated slits. Damage to the pipe wall often caused an enlarged orifice with discharge greater than that through carefully prepared slits of the same length. Variation in discharge was reduced to a reasonable value only by using 0.005-inch blade stock and a jig to align the pipe axially with the blade.

With reference to the precision with which slits can be formed, if a knife blade pierces the wall of plastic pipe with no lateral movement, the length of the slit should be the exact length of the blade. When the blade edge severs the material, elastic deformation apparently allows the slit to close fully when the blade is withdrawn. Full closure did not always occur when 0.020-inch blade stock was used. For the slits made with the 0.020-inch blade stock, the Reynolds number ($N_R = V\delta/\nu = Q/s\nu$) associated with drip flow and jet flow was of the same magnitude as was found for the more perfectly formed slits. The opening of the slit resulting from knife damage was of such small magnitude (0.020 inch or less) that surface tension effects were equally influential for closed slits as for the slightly opened ones.

Summary

The discharge rate of water from longitudinal slits in polyethylene plastic pipe was measured over a selected range of pipe sizes, slit lengths, and pressures. For the variable area orifice configuration represented by a slit in an elastic-wall pipe, the discharge rate was related to pertinent quantities of the fluid properties, pipe, and slit dimensions. Pipe specimens representing two ASTM types, Type I and Type II, were used in the study.

Depending on relative slit size and pressure, two types of flow from a slit opening are possible. For relatively low pressure and small slit size, drip flow will exist. As either pressure or slit size is increased, the flow will shift to a clean jet of fluid. Discharge rate increases with head to the third power in the jet flow region for both types of pipe. At high pressures and for large slits the discharge rate tapers off from a third power in the jet flow region to a lesser value. In this region, however, the configuration of the slit is greatly distorted and there is danger of rupturing the pipe wall. For Type I and Type II pipe the maximum safe pressure and slit size is identified by the division of linear and non-linear regions shown in Figures 8 and 9.

For the linear jet flow region, graphic analysis was used to find a suitable equation model for relating discharge rate to the independent variables. Because of the variation in the area of slit openings with changes in pressure, no attempt was made to find coefficients commonly used with rigid orifices. The discharge rate was related to fluid properties, pipe wall and slit dimensions, and pressure with the equation model $Q = C\ (H)^j\ (s/t)^m\ (r/t)^n$ found by preliminary graphic analysis to be appropriate for the jet flow region.

The dimensionless ratio s/t (ratio of slit length to wall thickness) was found to be a useful parameter to identify the flow regimes.

The mean width of the slit opening, δ, a pertinent quantity, was not measured directly during the course of the experiments. However, a Reynolds number based on it was calculated indirectly. Based on the continuity equation and known volumetric discharge rate and slit length, a Reynolds number $N_R = Q/s\nu = V\,\delta/\nu$ was used. Drip flow occurred when N_R was less than 30; jet flow occurred for N_R greater than 100.

Prediction equation (b) for Type I pipe

$$Q = 1.14 \times 10^{-10} (s/t)^{3.91} (r/t)^{1.72} (H)^{3.19} \tag{b}$$

and equation (d) for Type II pipe

$$Q = 1.25 \times 10^{-10} (s/t)^{3.68} (r/t)^{0.61} (H)^{3.13} \tag{d}$$

were derived with multiple correlation coefficients $R^2 = 0.95$ and 0.92, respectively, for the two types of pipe. The validity of the prediction equations was verified by applying them to independent slit discharge data for both pipe types. Tables of solutions to the prediction equations are presented in the Appendix for r/t values corresponding to the pipe dimensions for commercial standards CS197-60 and CS255-63. The range of pressure head and relative slit size values in the tables of solution corresponds to the range of validity of the equations as defined by the linear jet flow region in Figures 8 and 9.

A 0.020-inch-thick knife blade produced slits with widely varying discharge rates due to damage to the wall fiber when the blade entered the pipe wall. The use of 0.005-inch blade stock reduced random variation in slit discharge from 38 per cent to 12 per cent. Only discharge data obtained from slits made with the 0.005-inch blade stock were used to generate prediction relations for jet-type flow.

Measurement of the modulus of elasticity of pipe specimens was accomplished by short-term tensile loading with strain measured by resistance strain gages bonded to the pipe wall. For Type I pipe the modulus of elasticity corrected to 72.3° F. was 32,500 psi and 34,000 psi for the two resins used in development of prediction equations. For Type II pipe the modulus for both specimens was found to be near 70,000 psi.

It was assumed that the effect of variation in modulus of elasticity due to temperature in the range of 65° to 85° F. and differing resin density was not greater than the known random variation in slit discharge due to imperfections in slit formation and experimental error. The results of the regression and correlation analysis verified the assumption. High correlations ($R^2 > 0.90$) were obtained with pooled data for each type of pipe.

Appendix

Discharge Through Slit in Polyethylene Plastic Pipe

Solutions to Prediction Equation (b) for Type I Pipe and Equation (d) for Type II Pipe

APPENDIX TABLE 1.—Slit Discharge for Type I Pipe, R/T = 2.85*

Q, gpm	H, ft.	r/t	s/t
.0067	40.0	2.85	3.0
.0098	45.0	2.85	3.0
.0137	50.0	2.85	3.0
.0185	55.0	2.85	3.0
.0244	60.0	2.85	3.0
.0316	65.0	2.85	3.0
.0400	70.0	2.85	3.0
.0499	75.0	2.85	3.0
.0613	80.0	2.85	3.0
.0744	85.0	2.85	3.0
.0893	90.0	2.85	3.0
.0054	20.0	2.85	5.0
.0110	25.0	2.85	5.0
.0197	30.0	2.85	5.0
.0323	35.0	2.85	5.0
.0495	40.0	2.85	5.0
.0721	45.0	2.85	5.0
.1009	50.0	2.85	5.0
.1368	55.0	2.85	5.0
.1806	60.0	2.85	5.0
.2332	65.0	2.85	5.0
.0022	10.0	2.85	7.0
.0080	15.0	2.85	7.0
.0202	20.0	2.85	7.0
.0411	25.0	2.85	7.0
.0737	30.0	2.85	7.0
.1205	35.0	2.85	7.0
.1846	40.0	2.85	7.0
.2690	45.0	2.85	7.0
.0006	5.0	2.85	9.0
.0059	10.0	2.85	9.0
.0215	15.0	2.85	9.0
.0540	20.0	2.85	9.0
.1101	25.0	2.85	9.0
.1970	30.0	2.85	9.0
.3224	35.0	2.85	9.0

*These values apply to 1/2-, 3/4-, 1-, and 1 1/4-inch pipe rated 100 psi with dimensions in conformance with CS197-60.

APPENDIX TABLE 2.—Slit Discharge for Type I Pipe, R/T = 3.88*

Q, gpm	H, ft.	r/t	s/t
.0114	40.0	3.88	3.0
.0166	45.0	3.88	3.0
.0232	50.0	3.88	3.0
.0315	55.0	3.88	3.0
.0416	60.0	3.88	3.0
.0537	65.0	3.88	3.0
.0681	70.0	3.88	3.0
.0849	75.0	3.88	3.0
.1043	80.0	3.88	3.0
.1266	85.0	3.88	3.0
.1519	90.0	3.88	3.0
.0092	20.0	3.88	5.0
.0188	25.0	3.88	5.0
.0336	20.0	3.88	5.0
.0550	35.0	3.88	5.0
.0842	40.0	3.88	5.0
.1227	45.0	3.88	5.0
.1717	50.0	3.88	5.0
.2328	55.0	3.88	5.0
.3074	60.0	3.88	5.0
.3970	65.0	3.88	5.0
.0038	10.0	3.88	7.0
.0137	15.0	3.88	7.0
.0343	20.0	3.88	7.0
.0700	25.0	3.88	7.0
.1254	30.0	3.88	7.0
.2052	35.0	3.88	7.0
.3143	40.0	3.88	7.0
.4579	45.0	3.88	7.0
.0011	5.0	3.88	9.0
.0100	10.0	3.88	9.0
.0366	15.0	3.88	9.0
.0919	20.0	3.88	9.0
.1874	25.0	3.88	9.0
.3354	30.0	3.88	9.0
.5488	35.0	3.88	9.0

*These values apply to 1/2-inch pipe rated 75 psi with dimensions in conformance with CS197-60.

APPENDIX TABLE 3.—Slit Discharge for Type I Pipe, R/T = 4.20*

Q, gpm	H, ft.	r/t	s/t
.0131	40.0	4.20	3.0
.0190	45.0	4.20	3.0
.0266	50.0	4.20	3.0
.0361	55.0	4.20	3.0
.0477	60.0	4.20	3.0
.0616	65.0	4.20	3.0
.0781	70.0	4.20	3.0
.0973	75.0	4.20	3.0
.1196	80.0	4.20	3.0
.1451	85.0	4.20	3.0
.1742	90.0	4.20	3.0
.0105	20.0	4.20	5.0
.0215	25.0	4.20	5.0
.0385	30.0	4.20	5.0
.0630	35.0	4.20	5.0
.0965	40.0	4.20	5.0
.1406	45.0	4.20	5.0
.1969	50.0	4.20	5.0
.2669	55.0	4.20	5.0
.3525	60.0	4.20	5.0
.4551	65.0	4.20	5.0
.0043	10.0	4.20	7.0
.0157	15.0	4.20	7.0
.0394	20.0	4.20	7.0
.0803	25.0	4.20	7.0
.1438	30.0	4.20	7.0
.2352	35.0	4.20	7.0
.5250	45.0	4.20	7.0
.3604	40.0	4.20	7.0
.0013	5.0	4.20	9.0
.0115	10.0	4.20	9.0
.0420	15.0	4.20	9.0
.1053	20.0	4.20	9.0
.2148	25.0	4.20	9.0
.3846	30.0	4.20	9.0
.6292	35.0	4.20	9.0

*These values apply to 3/4-, 1-, and 1 1/4-inch pipe with dimensions in conformance to CS197-60.

APPENDIX TABLE 4.—Slit Discharge for Type II Pipe, R/T = 5.19*

Q, gpm	H, ft.	r/t	s/t
.0041	50.0	5.19	3.0
.0055	55.0	5.19	3.0
.0072	60.0	5.19	3.0
.0093	65.0	5.19	3.0
.0117	70.0	5.19	3.0
.0145	75.0	5.19	3.0
.0178	80.0	5.19	3.0
.0215	85.0	5.19	3.0
.0257	90.0	5.19	3.0
.0305	95.0	5.19	3.0
.0358	100.0	5.19	3.0
.0054	30.0	5.19	5.0
.0088	35.0	5.19	5.0
.0133	40.0	5.19	5.0
.0193	45.0	5.19	5.0
.0268	50.0	5.19	5.0
.0361	55.0	5.19	5.0
.0474	60.0	5.19	5 0
.0610	65.0	5.19	5.0
.0769	70.0	5.19	5.0
.0954	75.0	5.19	5.0
.1168	80.0	5.19	5.0
.1412	85.0	5.19	5.0
.1689	90.0	5.19	5.0
.2000	95.0	5.19	5.0
.0053	20.0	5.19	7.0
.0106	25.0	5.19	7.0
.0187	30.0	5.19	7.0
.0303	35.0	5.19	7.0
.0460	40.0	5.19	7.0
.0665	45.0	5.19	7.0
.0925	50.0	5.19	7.0
.1247	55.0	5.19	7.0
.1638	60.0	5.19	7.0
.2104	65.0	5.19	7.0
.2654	70.0	5.19	7.0
.3294	75.0	5.19	7.0
.4032	80.0	5.19	7.0
.0015	10.0	5.19	9.0
.0054	15.0	5.19	9.0
.0133	20.0	5.19	9.0
.0266	25.0	5.19	9.0
.0472	30.0	5.19	9.0
.0764	35.0	5.19	9.0
.1161	40.0	5.19	9.0
.1679	45.0	5.19	9.0
.2335	50.0	5.19	9.0
.3147	55.0	5.19	9.0
.4133	60.0	5.19	9.0
.5310	65.0	5.19	9.0
.6697	70.0	5.19	9.0

*These values apply to 1/2-inch pipe rated 75 psi with dimensions in conformance to CS197-60, and 80 psi-rated pipe with dimensions in conformance to CS255-63.

APPENDIX TABLE 5.—Slit Discharge for Type II Pipe, R/T = 5.75*

Q, gpm	H, ft.	r/t	s/t
.0043	50.0	5.75	3.0
.0059	55.0	5.75	3.0
.0077	60.0	5.75	3.0
.0099	65.0	5.75	3.0
.0125	70.0	5.75	3.0
.0155	75.0	5.75	3.0
.0189	80.0	5.75	3.0
.0229	85.0	5.75	3.0
.0274	90.0	5.75	3.0
.0325	95.0	5.75	3.0
.0381	100.0	5.75	3.0
.0058	30.0	5.75	5.0
.0093	35.0	5.75	5.0
.0142	40.0	5.75	5.0
.0205	45.0	5.75	5.0
.0285	50.0	5.75	5.0
.0385	55.0	5.75	5.0
.0505	60.0	5.75	5.0
.0649	65.0	5.75	5.0
.0818	70.0	5.75	5.0
.1016	75.0	5.75	5.0
.1243	80.0	5.75	5.0
.1503	85.0	5.75	5.0
.1798	90.0	5.75	5.0
.2129	95.0	5.75	5.0
.0056	20.0	5.75	7.0
.0112	25.0	5.75	7.0
.0199	30.0	5.75	7.0
.0322	35.0	5.75	7.0
.0490	40.0	5.75	7.0
.0708	45.0	5.75	7.0
.0985	50.0	5.75	7.0
.1328	55.0	5.75	7.0
.1744	60.0	5.75	7.0
.2240	65.0	5.75	7.0
.2825	70.0	5.75	7.0
.3507	75.0	5.75	7.0
.4292	80.0	5.75	7.0
.0016	10.0	5.75	9.0
.0057	15.0	5.75	9.0
.0141	20.0	5.75	9.0
.0284	25.0	5.75	9.0
.0502	30.0	5.75	9.0
.0814	35.0	5.75	9.0
.1236	40.0	5.75	9.0
.1787	45.0	5.75	9.0
.2486	50.0	5.75	9.0
.3350	55.0	5.75	9.0
.4399	60.0	5.75	9.0
.5653	65.0	5.75	9.0
.7129	70.0	5.75	9.0

*These values apply to 3/4-, 1- and 1 1/4-inch pipe with dimensions in conformance with CS197-60.

APPENDIX TABLE 6.—Slit Discharge for Type II Pipe, R/T = 7.50*

Q, gpm	H, ft.	r/t	s/t
.0051	50.0	7.50	3.0
.0069	55.0	7.50	3.0
.0091	60.0	7.50	3.0
.0116	65.0	7.50	3.0
.0147	70.0	7.50	3.0
.0182	75.0	7.50	3.0
.0223	80.0	7.50	3.0
.0269	85.0	7.50	3.0
.0322	90.0	7.50	3.0
.0382	95.0	7.50	3.0
.0448	100.0	7.50	3.0
.0068	30.0	7.50	5.0
.0110	35.0	7.50	5.0
.0167	40.0	7.50	5.0
.0241	45.0	7.50	5.0
.0336	50.0	7.50	5.0
.0452	55.0	7.50	5.0
.0594	60.0	7.50	5.0
.0763	65.0	7.50	5.0
.0963	70.0	7.50	5.0
.1195	75.0	7.50	5.0
.1462	80.0	7.50	5.0
.1768	85.0	7.50	5.0
.2114	90.0	7.50	5.0
.2504	95.0	7.50	5.0
.0066	20.0	7.50	7.0
.0132	25.0	7.50	7.0
.0234	30.0	7.50	7.0
.0379	35.0	7.50	7.0
.0576	40.0	7.50	7.0
.0833	45.0	7.50	7.0
.1159	50.0	7.50	7.0
.1562	55.0	7.50	7.0
.2051	60.0	7.50	7.0
.2635	65.0	7.50	7.0
.3323	70.0	7.50	7.0
.4124	75.0	7.50	7.0
.5048	80.0	7.50	7.0
.0019	10.0	7.50	9.0
.0067	15.0	7.50	9.0
.0166	20.0	7.50	9.0
.0334	25.0	7.50	9.0
.0591	30.0	7.50	9.0
.0957	35.0	7.50	9.0
.1454	40.0	7.50	9.0
.2102	45.0	7.50	9.0
.2924	50.0	7.50	9.0
.3940	55.0	7.50	9.0
.5174	60.0	7.50	9.0
.6648	65.0	7.50	9.0
.8385	70.0	7.50	9.0

*These values apply to 3/4-, 1-, and 1 1/4-inch pipe rated 80 psi with dimensions in conformance to CS255-63.

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